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Research on optimization of valve open time of the launch barge's ballast tanks

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Abstract: Launch barge is an effective tool for transporting ship segments from one place to another in shipyards. During shifting of segments onto a barge, the slideway on the barge's deck must be adjusted to maintain the same level as the wharf and also the barge must be kept level by adjusting the water in the ballast tanks. When to open the adjusting valves is an important factor influencing the barge's trim during the water-adjustment process. Because these adjustments are complex a mathematical model was formulated,after analyzing the characteristics of the process of moving the segments onto the barges deck, and considering the effects of this movement's speed and variations in tidal levels during the move. Then the model was solved by the penalty function method, the grid method, and improved simulated annealing, respectively. The best optimization model and its corresponding solution were then determined. Finally, it was proven that the model and the method adopted are correct and suitable, by calculating and analysing an example.

Keywords: launch barge; stowage; penalty function method; simulated annealing method; grid method
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1 Introduction

Launch barge is a highly-efficient marine traffic tool on transporting ship products substantially. In the process of transporting products onto the barge, the barge is subjected to variable pressures and moments induced by the products. So the ballast tanks' water must be adjusted frequently to keep the barge under some required floating condition. Usually, the adjustment is realized by hand based on the operator's experience of observing the six drafts of the port, starboard at bow, amidships and stern. But commonly there are so many ballast tanks in the barge that it makes the manual operation complicated and low efficiency [1].

Each ballast tank's liquid level of the barge can be obtained real-time through establishing some appropriate mathematical model combined with a well-chosen optimization algorithm [2-3]. But water adjusting valves' open or close is not instant, and not expected excessively frequent during the transporting process as long as the barge has good floating condition and enough strength. Generally there are two valve operating modes to deal with this problem. One mode is that at the initial transporting time, water adjusting valves are all closed. During the transporting process, some factors such as barge draft and strength are being monitored real-time. If one of these factors exceeds it's allowable value, the transporting operation must be stopped and some adjusting valves are opened according to each ballast tank's calculated adjusting water volume needed at that time. When all factors are allowable, all valves are closed and the transporting operation goes on again. And repeat above steps until the transported product arrives at the designated position. The other mode is to assume product's next stop position is given, the adjusting water volume needed from current position to the next can be calculated. The adjusting valves will open and close at suitable time before product arrives at the next stop position. During the process of transporting, those factors mentioned above are monitored and dealt with as the same. Obviously, the second mode shows better characters that the new force and moment added onto the barge are balanced by adjusting ballast tanks' water, and it can decrease the number of valves' open and close times.

Whichever mode is chosen, a problem always exists: different adjusting valve open time will result in different barge floating condition during the water adjustment process. How to confirm the valve open time in the second mode is discussed mainly in this paper, finally the floating conditions of the barge are always well in the adjusting process, and the product can be transported onto the barge more quickly on the premise of ensuring safety.

2 Problem analysis and modeling

Schematic diagram of transporting products onto the barge is given as Fig.1 in order to explain this process more clearly, in which, the product needs to be

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transported onto the barge from position A to position B. In this process the slideway on barge deck must always be kept on the same level as the wharf as far as possible, considering the effect of the transporting speed, and the variable tidal level. The ballast tanks' information from position *A* to position *B*, for example, the number of ballast tanks and the ballast water, can be known from Ref.[2].

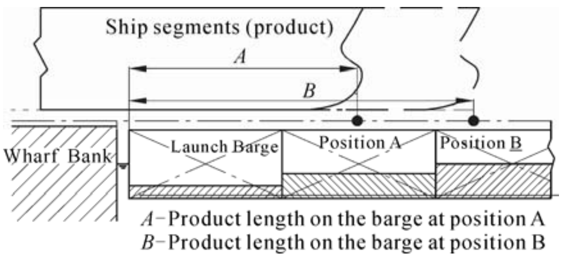

Fig.1 Schematic diagram of transporting products onto the barge

Through choosing open time *Ts* of the ballast tanks' valves, namely, $Ts=[ts_1,ts_2,\cdots,ts_N]^{\mathrm{T}}$, a simple optimization model can be founded as follows:

$$\begin{cases} \min \quad f(Ts)=F(Ts) \\ \text{s.t.} \quad g_1(Ts)=ts_i+\Delta t_i-t_{\max}\le 0 \quad i=1,2,\cdots,N \\ \qquad\; g_2(Ts)=-ts_i\le 0 \qquad\qquad\quad i=1,2,\cdots,N \end{cases} \quad (1)$$

where $\Delta t_i=\Delta w_i/r_i$.

$F(Ts)$— function for characterizing the barge floating condition in the period of transporting products from position A to position B;

ts_i— valve open time for ballast tank *i* ;

Δt_i— adjustment completion time for ballast tank *i* ;

N— amount of ballast tanks needed to be adjusted;

$t_{\max}$— allowable adjusting time scope for ballast tanks;

Δw_i— adjusting water volume needed for ballast tank *i* from position *A* to position *B*;

r_i— valve flow rate for ballast tank *i* .

The key of the above model is how to choose and compute the function for characterizing the barge floating condition $F(Ts)$. The barge trim and mean draft should be considered in this function because the slideway on barge deck must always be kept on the same level with that on the wharf as far as possible during the transport process. Additionally, different treatment methods of $F(Ts)$ will spend different computing time and bring about different results. For selecting the best expression of $F(Ts)$, two treatment modes are studied as follows. Mode one is mainly to express the barge's floating condition of the whole adjusting process. Obviously it will increase the calculation amount, but it matches the real engineering requirement better. As to Mode two, what it expresses is the barge's floating condition at some moment. Although it decreases the calculation amount, it can only obtain a group of valve open time to satisfy the best floating condition at that moment after optimization, and at other moments, the barge is perhaps under worse floating condition. So some special treatments are required after optimization for Mode two.

To facilitate the presentation, $t_{\max}$ is supposed to be divided into *M* portions.

2.1 Mode one

The function for characterizing the floating condition is given as follows:

$$F(Ts)=\mathrm{Max}\left(\frac{|\mathrm{Trim}_i|}{\mathrm{Trim}_{\max}}+\frac{|d_i-d_r|}{d_0}\right) \quad i=0,1,\cdots,M \quad (2)$$

In which, Trim_i and d_i denote barge trim and mean draft at time t_i at valve open time *Ts*; respectively; $\mathrm{Trim}_{\max}$ denotes the biggest allowable trim; d_r denotes the required draft at which the barge can be kept on the same level with the wharf at time t_i; d_0 denotes barge mean draft when the product is located at position A; Max denotes a function which can get the maximum value of its followed formula.

It is obvious that the computation of Trim_i and d_i is the key to confirm the function for characterizing the floating conditions and it is related to valve open time *Ts*, transporting speed *Vs* and variable tide level h_{tide}.

If the valve open time *Ts* is given, the water volume which has already been adjusted until time t_i for each ballast tank can be worked out. Accordingly, the water volume of each ballast tank at this time can be worked out as Eq.(3).

$$V_j=\begin{cases} V_{0j}, & t_i\le ts_j; \\ V_{0j}+r_j\cdot(t_i-ts_j)\cdot\dfrac{\Delta w_j}{|\Delta w_j|},, & ts_j<t_i<ts_j+\Delta t_j; \\ V_{0j}+r_j\cdot\Delta t_j\cdot\dfrac{\Delta w_j}{|\Delta w_j|}, & t_i\ge ts_j+\Delta t_j; \end{cases}$$
$$i=0,1,\cdots,M; \quad j=1,2,\cdots,N. \quad (3)$$

In which, V_j and V_{0j} denote the water volume of ballast tank *j* at time t_i and at the initial time, respectively.

If the relationship function between transporting speed and time is given, namely, $Vs=S(t)$, the transporting distance ΔL from position *A* can be worked out at time t_i, then the weight and center of gravity of the product transported onto the barge can be calculated considering the product's weight curve.

The weight and center of gravity of the whole barge can be obtained at this time easily when each ballast tank's water volume and the weight and center of gravity of the product transported onto the barge are known at time t_i. So the parameters d_i and Trim_i of barge floating condition can be calculated easily based on the principle of ship statics[4].

If the relationship function between tidal level with time is known, namely, $h_{\mathrm{tide}} = H(t)$, the barge mean draft required d_r at time t_i can be worked out as Eq.(4):

$$d_r = d_0 - H(0) + H(t_i) . \tag{4}$$

2.2 Mode two

The function The function for characterizing the floating condition is given as follows:

$$F(Ts, t_i) = \frac{|\mathrm{Trim}_i|}{\mathrm{Trim}_{\max}} + \frac{|d_i - d_r|}{d_0} \quad i = 0,1,\cdots, M-1, M \tag{5}$$

If Eq.(5) is adopted as objective function, the best valve open time can be obtained through solving the optimization model Eq.(1) when the barge is under the best floating condition. Thus, *M+1* groups of optimal time $\{Ts_0, Ts_1, \cdots, Ts_M\}$ can be got through solving the optimization models for *M+1* times. As to each group Ts_j, the biggest value of the function for characterizing the barge floating condition can be solved, namely $\rho_j = \max\left[F(Ts_j, t_i)\right]_{i=0,1,\cdots,M}$. Then the smallest $\rho_{\min}$ can be found by comparing these values, and so its corresponding valve open time Ts_j is the final optimal result.

3 Model solving method

Penalty function method, grid method and improved simulated annealing method are adopted to solve the optimization model respectively and their principles and details of each algorithm are introduced as follows.

3.1 Penalty function method

Eq.(1) can be transformed to unconstrained optimization problems by introducing penalty[5] factor r_k as follows:

$$\min F(Ts, r_k) = f(Ts) + r_k \cdot \sum_{i=1}^{2} \left\{ \frac{|g_i(Ts)| + g_i(Ts)}{2} \right\}^2 . \tag{6}$$

The unconstrained optimization problems (6) can be solved in turn through regulating r_k (increasing gradually), and when $k \to \infty$, the optimal solution of Eq.(6) is the final solution of Eq.(1). The penalty factor is usually taken as

$$r_{k+1} = r_k \cdot c \qquad k = 0,1,2\cdots \tag{7}$$

In which, $c \in [4,10]$, $r_0 > 0$.

3.2 Analysis of results

It can be known from Eq.(1) that the allowable limit of the open time of the *i* th ballast tank's valve is $\left[0, t_{\max} - \Delta t_i\right]$. The time limit is divided into *M* portions, supposing the open time of the ith ballast tank's valve is only taken from one of the M_1+1 diversion points, then all valves' open time can be denoted as $Ts = \left[ts_{0j_1}, ts_{1j_2}, \cdots, ts_{Nj_N}\right] \quad j_1, j_2, \cdots j_N \in [0, M_1]$. It is obvious that there are M_1^N combinations. Each combination's value of the function for characterizing the floating condition as shown in Eq.(2) can be obtained, the combination of the smallest value can be found by comparing these values and this combination can be thought as the optimal solution of Eq.(1).

Theoretically, $M_1 \to +\infty$, the solution based on the above method is the optimal solution of Eq (1). It is obvious that the number of the combination grows rapidly with the increasing of M_1 and it results in the calculating time increasing greatly. So M_1 should be taken with a proper value and in this paper, M_1=100, the number of the adjusting ballast tanks is no more than 7.

3.3 Analysis of results

Simulated annealing is a stochastic global optimization algorithm. Its basic idea is that an optimization problem is made as a physical system and the object function $f(x)$ as the system energy $E(x)$, and the system is gradually cooled down from a high initial temperature T_0>0, and when the system reaches the lowest energy state in the end, the global optimal solution of the problem is considered to be found.

The following terms must be satisfied to get the global optimal solution for simulated annealing: the initial temperature must be high enough under which the system can reach all states with the same probability; and the cooling rate must be slow enough to make the system reach quasi-equilibrium state at every temperature; termination temperature approaches zero degree. Actually, as these terms can not be satisfied entirely, simulated annealing method can only find approximate global optimal solution with some certain probability, otherwise, different methods to generate new solution will have a significant effect on the algorithm convergence.

As to the optimization model in this paper, such treatment methods are adopted:

1) Cooling mode.

$$T_{k+1} = \alpha \cdot T_k , \tag{8}$$

where α is the cooling factor which is commonly taken as 0.95 ~ 0.98.

2) Method to generate new solution.

Supposing the current decision variable is $Ts_k = (ts_1, ts_2, \cdots, ts_N)^{\mathrm{T}}$, a random component ts_r is chosen from the current solution to generate random disturbance:

$$ts_r' = ts_r + \mathrm{Rand} \cdot \mathrm{Scale} \cdot (t_{\max} - \Delta t_r) . \tag{9}$$

In which, "Rand" is a random number in the range of [-1, 1], "Scale" is the neighborhood scale factor which is taken as 0.8.

Then, boundary treatment is done to the value of Eq.(9), and then the new solution Ts_{k+1} can be obtained as follows:

$$ts_r = \begin{cases} t_{\max} - \Delta t_r + ts_r' & ts_r' < 0 \\ ts_r' & 0 \le ts_r' \le t_{\max} - \Delta t_r \\ ts_r' + \Delta t_r - t_{\max} & ts_r' > t_{\max} - \Delta t_r \end{cases} . \tag{10}$$

3) Acceptance criteria of the new solution[6] (Metropolis criteria).

The transition probability of the new solution can be obtained from Eq.(11) when the temperature is T. The new solution will be accepted if $p > \eta$ (η is a random number uniformly distributing in the space interval (0, 1)), or else be abandoned.

$$p = \begin{cases} 1.0 & f(Ts_{k+1}) \le f(Ts_k) \\ \exp\left[\dfrac{f(Ts_k) - f(Ts_{k+1})}{T}\right] & f(Ts_{k+1}) > f(Ts_k) \end{cases} \tag{11}$$

4) Termination criteria.

After the temperature is continuously cooled down for many times, the object function value does not decrease any longer.

4 Example analysis

There is a cuboid launch barge, whose length L_{bp} is 105 m, breadth B is 63 m, molded depth D is 7.8 m, and there are 30 ballast tanks. The product which is ready to be transported onto the barge is about 13 000 t weight and 100 m long and is distributed uniformly for the weight load.

Schematic diagram of transporting products onto the barge is shown as Fig.1. The transporting speed Vs is taken as 0.8 m/min. And the moments of the barge staying in position A and position B are t_A=0 and t_B=10.0 min, respectively, so $t_{\max}$ can be obtained by t_B minus t_A, namely, $t_{\max} = t_B - t_A$ =10.0 min.

The liquid level height of each ballast tank and the mean draft of the barge are already known when the product is in position A. And these data in position B can be obtained based on the method adopted in Ref.[2].

In this paper, Mode one of processing the function for characterizing the floating condition is adopted to solve this problem by penalty function method, grid method and improved simulated annealing method, respectively, as to Mode two only penalty function method is used to solve this problem. The results of these methods are shown as Table 1. In which, as to grid method, the number of M_1 is 20, so the combination number is $M_1^N = 20^5$=3 200 000; as to improved simulated annealing, some parameters are given as follows: the initial temperature T_0= 20, the Markov chain length $L_{\max}$=50, the cooling factor α = 0.99.

Table 1 Optimal results of valve open time of ballast tanks

Number of the ballast tanks	Regulating water content /t	Valve flow rate /(t/min)	Mode one/min			Mode two/min
			Penalty function method	Grid method	Improved Simulated annealing	Penalty function method
1	43.5	100.0	0.075	0.000	1.416	5.725
2	-10.3	100.0	0.000	0.000	0.215	6.625
3	-299.4	100.0	0.106	0.375	6.994	3.325
4	-469.7	100.0	2.474	5.782	0.004	0.125
5	-293.7	100.0	6.765	3.021	4.270	6.500
Value of object function $F(Ts)$			0.145	0.135	0.100	0.370

Note: The value of object function $F(Ts)$ about Mode two is calculated by the function of Mode one.

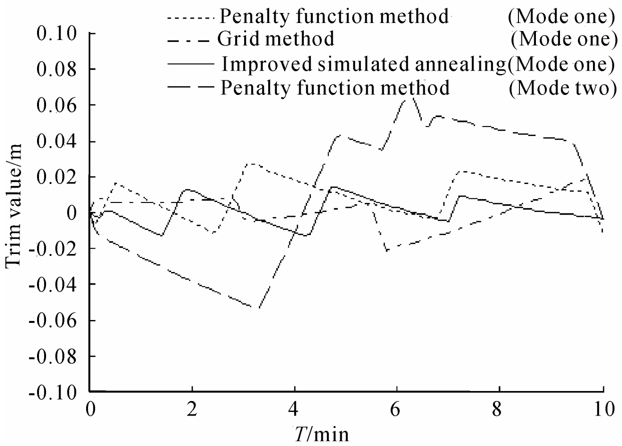

Fig.2 Trim value curve of the barge vs. time

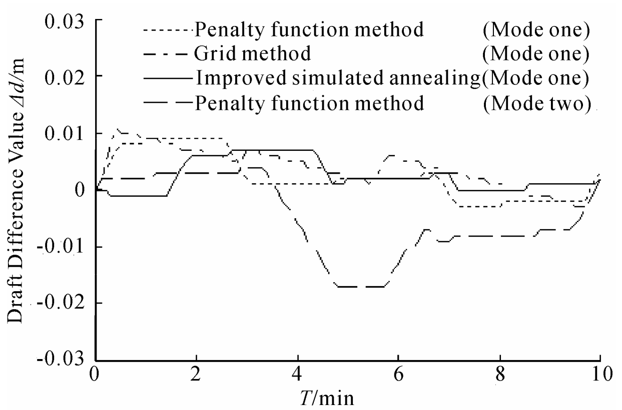

Fig.3 Difference value curve between real-time and required draft of the barge vs. time

Some conclusions can be drawn from Fig.2 and Fig.3:

1) It can be seen from the results by using Mode two that the floating conditions of the barge is the poorest, the biggest trim value is more than 0.060 m and the maximal difference value between real-time and required draft is more than 0.015 m.

2) It can be seen from the results by using Mode one that the floating conditions of the barge are better, the trim values are less than 0.03 m and the difference value is less than 0.010 m.

3) As to Mode one, it can be seen from the results that grid method or improved simulated annealing method are better than penalty function method to solve this problem.

5 Conclusions

All the optimal results obtained from the methods used in this paper can play some certain roles in maintaining the floating conditions of the barge, and the treatment of Mode one is better than Mode two as to this problem. Although the results obtained from grid method can have a good floating condition, the calculating time will increase rapidly with the increasing number of the ballast tanks or the regulating time's uniform division portions. So the grid method is suited only for less number of the ballast tanks or the regulating time's uniform division portions; improved simulated annealing method is a stochastic global optimization algorithm, the calculating time is relatively longer and the result is well enough to this problem; as to penalty function method, the calculating time is relatively shorter but the result is poorer than other methods to this problem. So penalty function method can be adopted when the required calculating time is short and the floating conditions' limitation is low; otherwise grid method or improved simulated annealing should be adopted.

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下水驳船调载阀门开关时间优化算法研究

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摘　要：利用下水驳船移运船舶产品是一种提高船厂修造船能力的有效方式. 在船舶产品移运上驳过程中，要求驳船通过调节自身压载水舱水量使驳船始终保持与码头岸边齐平. 在调载过程中，调节水舱阀门打开时间是影响驳船浮态的重要因素。本文通过对调载过程特征分析，并考虑产品上驳速度以及潮位变化等参数影响，建立了适当数学模型，分别采用惩罚函数法、网格法和模拟退火法进行求解. 通过实例计算与结果分析比较，确定了合适的优化模型和对应解法，同时也证明了本文所述方法的正确性和实用性.

关键词：下水驳船；配载；惩罚函数法；模拟退火法；网格法